Arnold Schwarzenegger
Governor

MAINTAIN, ENHANCE AND IMPROVE RELIABILITY OF CALIFORNIA'S ELECTRIC SYSTEM UNDER RESTRUCTURING

APPENDIX V

Nomogram Validation Application for CAISO Utilizing Phasor Technology - Functional Specification

PIER FINAL PROJECT REPORT

Prepared For:
California Energy Commission
Public Interest Energy Research Program

Prepared By:

Lawrence Berkeley National Laboratory

CERTS
CONSORTIUM FOR ELECTRIC RELIABILITY TECHNOLOGY SOLUTIONS

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Consortium for **E**lectric **R**eliability **T**echnology **S**olutions	Nomogram Validation Application For CAISO Utilizing Phasor Technology

FUNCTIONAL SPECIFICATION
DEVELOPED FOR THE
CALIFORNIA INDEPENDENT SYSTEM OPERATOR (CAISO)

Version 1.0
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Electric Power Group

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1.0 INTRODUCTION

The Consortium for Electric Reliability Technology Solutions (CERTS) was formed to research, develop, and disseminate new methods, tools, and technologies to protect and enhance the reliability of the U.S. electric power system under the emerging competitive electric market structures. The members of CERTS include Lawrence Berkley National Laboratory (LBNL), Oak Ridge National Laboratory (ORNL), the Power Systems Engineering Research Consortium (PSERC), Sandia National Laboratories (SNL), Pacific Northwest National Laboratory (PNNL) and Electric Power Group (EPG). Southern California Edison (SCE) acts as a CERTS Research Provider.

Reference, for this introduction, is also made to the U.S. Department of Energy's National Transmission Grid Study which noted the following:

- *DOE will work with industry to demonstrate cost-effective uses of dynamic transmission system analysis.*
- *PMAs and TVA should maintain their leadership of demonstration efforts to evaluate advanced transmission related technologies that enhance reliability and lower cost to customers.*
- *DOE will work with industry to develop innovative programs that fund transmission-related R&D, with special attention to technologies that are critical to addressing transmission bottlenecks.*

One of CERTS main efforts has been in the area of applying phasor technologies to various areas of the power system and industry. Much of the focus up to now has been toward utilizing and improving this technology in post-disturbance analysis. This specification will turn towards an application directed at 1) Improving the Dispatcher's analysis of operating limits, parameters and guidelines for reliable power system operations and 2) Validate that static nomograms are an effective tool for managing the operation of a transmission path in a dynamic interconnection and 3) Improve Real-Time System Operator's ability to monitor and operate a reliable power system through employment of dynamic nomograms and parameters.

2.0 CURRENT AND FUTURE APPLICATIONS OF PHASOR MEASUREMENTS

Table I: Time Table for Deployment of Synchronized Phasor Measurement Applications

	Stage 1 O/E-Dispatcher Applications Currently Being Deployed	Stage 2 Monitoring Applications Planned and Some Funded	Stage 3 Voltage/Frequency Control and Security Applications	Stage 4 Dynamic (angle) Control and Security Applications
Evolution (years)	1999-2002	2003-2004	2005-2008	2006-2010
Applications / Requirements	• OE Post Disturbance Analysis • Model Validation	• Real-Time Dynamics Monitoring • Stability-Nomogram Validation	• Remedial Action Scheme Validation • Relay Setting • PSS Monitoring/Tuning • Underfrequency Load Shedding • Islanding Supervision • PSS Operation/Coordination • Relay Adaptive Setting • Remedial Action Scheme Replacement	• FACTS Operation • New AGC/AVR Activation • LTC Blocking • Undervoltage-Load Shedding • Blackstart Coordination • Fault Detection, Location and Analysis • Dynamic Stability Response • Automatic Switchable Network • Response-based, Feedforward Wide-Area Control
Number of PMUs (WSCC)	40	60	150+	Same #
Delay Requirement (seconds)	4-500	4-500	0.1-100	0.001-0.1
System Reliability Requirements	Fully Redundant System	Fully Redundant System	TBD-Relay Type	TBD-Relay Type
Data Communications Bandwidth Requirement	Approximately 0.6 Mbits/s	Approximately 0.9 Mbits/s	TBD - SANDIA	TBD - SANDIA
Communications Security Requirements	TBD	TBD-SANDIA	TBD - SANDIA	TBD - SANDIA
PMU/PDC Expandability Requirements	Fully Expanded First Generation PMU/PDC	Second Generation PMU	Second Generation PDC	Third Generation PMU/PDC
Integration with Existing Communication Systems	FTP Server	SCADA, Substation Automation, DFRs	SCADA, Substation Automation, DFRs	SCADA, Substation Automation, DFRs and SERs
Costs				
PMU Installation	Use Current PMUs	TBD for 2nd Generation PMU	TBD for 2nd Generation PMU/PDC	TBD for 3rd Generation PMU/PDC
PDC Installation	$ 30k	TBD for 2nd Generation PMU	TBD for 2nd Generation PMU/PDC	TBD for 3rd Generation PMU/PDC
Communication Infrastructure	CAISO	TBD-SANDIA	TBD-SANDIA	TBD-SANDIA
O & M (PDC, Work Stations and Comm. Circuits)	TBD	TBD	TBD	TBD
Total Cost				

3.0 CERTS ROADMAP FOR SYNCHRONIZED PHASOR MEASUREMENT TECHNOLOGY

During the first quarter of Year 2000, Stakeholders representing utilities, manufacturers and academia met at Berkeley, California, to review and discuss the current status and future directions for security monitoring and control applications using synchronized phasor measurement technologies. The major recommendations coming from this Stakeholders meeting were adopted by CERTS in the preparation of the research work plan as shown in the figure below with its roadmap show in the first figure from the VAR summary. The figure below shows the major functional areas, ① to ⑥, in that where CERTS will be conducting research in during this multi-year project for the second phase of their research roadmap for Real Time Grid Reliability Management shown at center of Figure 1. Figure 1 also shows the interrelationships between each functional area and its corresponding development timeframe.

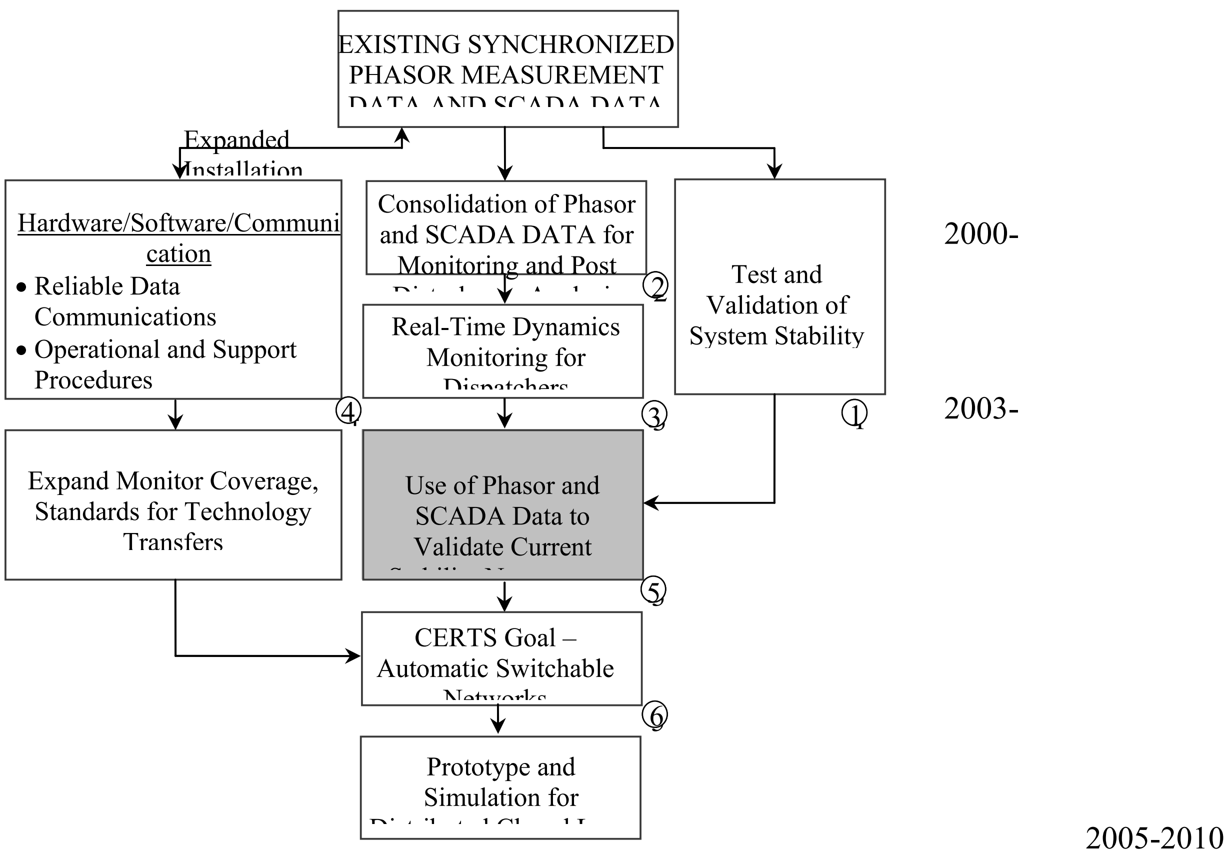

Figure 1: CERTS Functional Areas for Utilization of Phasor Measurement Technologies

The following is a brief description for each of the targeted six functional areas:

- Functional area number ① through ongoing DOE Outreach activities, CERTS is participating in comprehensive assessment and validation of the stability models used in WSCC planning. This involves extensive direct tests of WSCC system behavior.
- Functional area number ② will be PC-based workstations for post-disturbance analysis and system dynamic performance assessment using synchronized phasor measurements.
- Functional area number ③ will be for graphic-geographic wide-area real time monitoring using synchronized phasor measurements for the CAISO dispatchers.
- Functional area number ④ will create the necessary user and system support guides, manuals and standards for current Phasor Measurement infrastructures, and defines and evaluates alternatives to improve data communications and define second-generation phasor technology.
- Functional area number ⑤, shaded in Figure 2, will focus on enhancing the current deterministic stability nomograms using synchronized phasor measurements. Some of the algorithms from this area will be used for the dispatcher applications in functional area ③ during the next phase of this project and is the subject of this summary.
- Functional area number ⑥ is CERTS ultimate goal for applications using phasors. It will take advantage of the experiences learned during functional areas ① to ⑤ to conduct the necessary research and prototyping of new real time distributed control schemes, which will lead the way to future automatic switchable power networks.

4.0 NOMOGRAMS AND OPERATING LIMITS: AN OVERVIEW

A nomogram is described as a two-dimensional representation of the operational capabilities of a system when there is a tradeoff between two decision variables, such as the import or export of energy on one transmission path vs. the use of a second path. It represents the tradeoff one may have to make when transferring power between regions. The nomogram graphically defines a closed area within a plane that it is safe to operate in.

Nomogram development results in identification and illustration of the boundary between secure and insecure regions of operation for the single most limiting contingency. Traditionally, the limits of the nomogram are obtained through off-line studies with seasonal prediction of operating conditions and a predefined contingency list. These studies simulate a large number of contingencies at different transmission interface flow levels and under different outage conditions. Points on the nomogram curve are identified by repeated computer simulations over the set of contingencies (power-flows for static security assessment and step-by-step time simulation for transient stability assessment), varying one decision variable while holding the second decision variable constant, until the resulting flows violate established thermal, voltage and/or transient stability limits. Operating within the safe region of a nomogram should ensure that after a contingency event, the resulting flows would not cause a violation of the established thermal, voltage and/or stability limits. The computational complexity involved in this type of analysis is so extensive that these studies can be performed off-line only.

The nomogram below is representative of operating points from numerous operating study cases (Figure 2). It graphically indicates the simultaneous utilization of the two paths (in general) under a specific set of underlying assumptions regarding system configuration, loads and resource utilization. Points on the slope at the right provide the acceptable power flow relationships between the two paths, given the underlying contributing factors. These current nomogram parameters require manual updating depending on the system conditions.

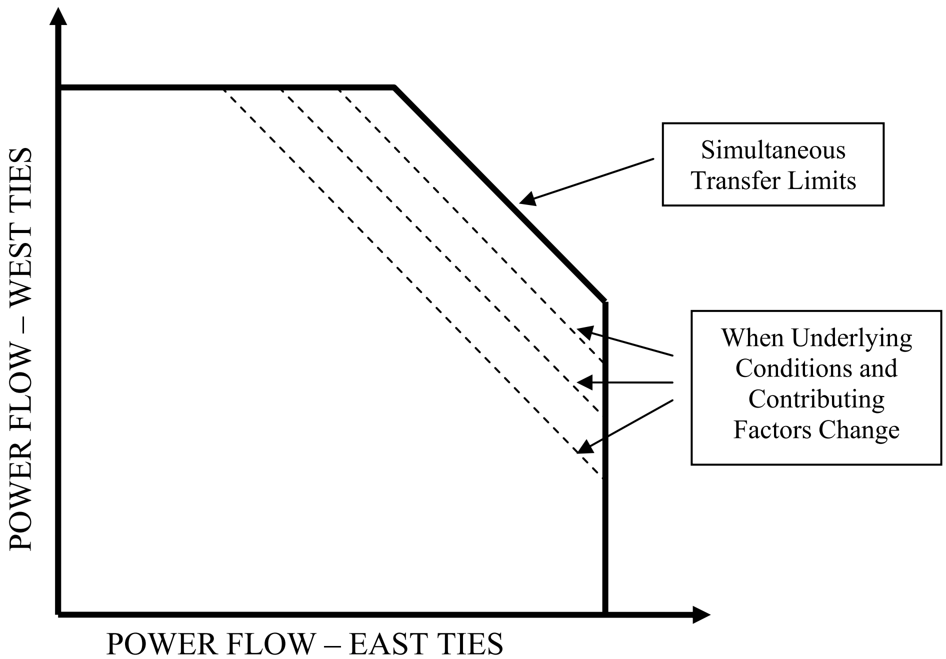

Figure 2: Example Nomogram Graphic (General).

4.1 VALIDATION OF EXISTING NOMOGRAMS AT CAISO

The CAISO manages the utilization of the transmission system with the aid of various nomograms. They enable the operator to (a) classify an operating point as secure or insecure, and (b) provide information on boundary proximity (how close the operating point is to the boundary). However, the nomograms have their limitations for two reasons: Firstly, while these nomograms are the work product of many studies covering so many operating points, they are designed to be utilized with only a couple of monitored parameters (e.g., power flows across transfer corridors). Hence the limits of these nomograms tend to be conservative for normal conditions. Moreover, unseen events may occur where the limits of the nomogram may not be directly applicable to the current system conditions. Secondly, due to the labor requirements the simulation procedure described above is normally used to obtain only a very few points on the boundary (mainly the corner points) and the remaining portions of the boundary are obtained by linearly interpolating between the points.

Phasor measurement data provide precise real-time direct monitoring capability of the power system dynamics at a very high rate. They also have the capability of accurately estimating and dynamically tracking various system parameters that provide a quantitative assessment of the health of system under the current operating condition and the prevalent contingency. A precise estimate of the load, generator and/or network parameters consequently allow for the most accurate assessment of the system limits of the current operating system. They therefore offer a means of validating the nomograms and other operating constraints. The value attained by phasor data is summarized in table II. The algorithms proposed for nomogram validation exploit some of these attributes.

Table II: Merits of Phasor Technology

- Directly measure phasor quantities (i.e., voltage and current magnitudes and angles) with high accuracy and very low noise - these quantities were previously computed via load flows and state estimator algorithms from telemetered data.
- Phasor data is captured at a very high sub-second rate which is well suited to track system dynamics (oscillatory swings), especially under transient conditions (the resolution of SCADA data is not adequate for capturing such dynamics). The highest frequency of interest for these swing dynamics is typically a few hertz.
- Data is accurately time tagged - timing information is crucial for detecting trends or parameter estimation (model fitting by operating engineers) from a window of observations.
- Phasor data across the system is synchronized and therefore is capable of providing wide-area snapshots of system dynamics for comparison and analysis purposes.

4.2 PROPOSED ALGORITHMS FOR VALIDATION

As mentioned earlier, the development of nomograms can be based on thermal limits as well as voltage and transient (angular) stability limits. At any given point in time, under normal conditions or during a transient event, the measured power flows thru the transfer paths are available and they define a unique point on the nomogram. This point may lay within or outside the existing nomogram boundaries and is consequently classified as being a secure or insecure operating point. Phasor data, along with selective SCADA data, can be used to validate nomograms that have been developed based on each of these considerations (i.e., voltage and transient stability) using concepts that follow one of the three methodologies described below. The three methodologies differ in computational complexity and the required degree of system visibility.

1. *Direct Measurements:* Most of the existing nomograms monitor the system with respect to a couple of key measured parameters in the system. These parameters generally are power flows across strategic corridors in the power network. Some advanced nomograms, like the SCIT nomogram, use more sophisticated metrics such as the inertia in the system to adapt their limits and consequently provide a more realistic representation of the true limits. The idea therefore is to utilize the improved visibility associated with phasor technology as additional metrics for monitoring the health of the system. In particular, the ability of phasor measurements to directly measure angles and voltages at a high rate as well as their ability to closely track system dynamics is of great value in assessing the system stability under current operating conditions and therefore validating the existing nomograms. The synchronization of these measurements also allows for a real time comparison of angles at different locations as large angle differences between

key points in the system are indicators of proximity to instability. This kind of real-time system dynamics observability isn't available with conventional SCADA data (i.e., SCADA data is not capable of capturing swing dynamics). Secondly, these measurements will provide a better indicator of the system health with respect to stability limits and therefore are more representative of the secure/insecure boundaries of the system. The same offline planning studies that have been used to develop the power flow limits for the existing nomograms may be used to identify important monitoring points for phasor data as well as their corresponding thresholds. This methodology is perhaps the most simplistic of the three in validating the nomograms; however, it relies on offline studies for defining limiting thresholds on the monitored data.

2. *Stability Indices:* While the methodology mentioned above directly uses the phasor measurements along with predetermined thresholds to characterize the health of the system and consequently validate the nomograms, this methodology uses phasor data to calculate critical metrics in the system that quantify the health of the system with respect to transient or voltage stability. In particular, synchronized phasor measurements provide an accurate sequence of snapshots of the power system behavior at a very high rate (30 samples per second) along with precise timing information. By continuously tracking phasor data thru a sliding time window of predetermined duration, it is possible to estimate certain load, generator and/or network parameters and deduce selected metrics that provide the most accurate up-to-date assessment of the system limits. These metrics, called 'stability indices', therefore offer a means for validating the stability classification based on the existing nomograms. A main advantage of this methodology is it does not rely on offline studies for its assessment.

3. *Online Security Assessment*: Unlike the above methodologies that do not depend on system model information for their stability assessment, this methodology combines measurements with the model information for a more comprehensive assessment. It, therefore, relies on a powerful computation engine for its assessment. In particular, with SCADA data and a power flow computation engine, it is possible to perform a contingency analysis and determine the reactive margins at each of the buses under the most current operating conditions.

The algorithms proposed below will exemplify how the various methodologies defined above may be utilized in validating nomograms that are based on transient (angular) stability and voltage stability limits respectively. They are summarized in the flowchart in figure 3 as well. However, the algorithm developed to validate a particular nomogram will be specifically tailored to that nomogram and may utilize any or all of the methodologies discussed above.

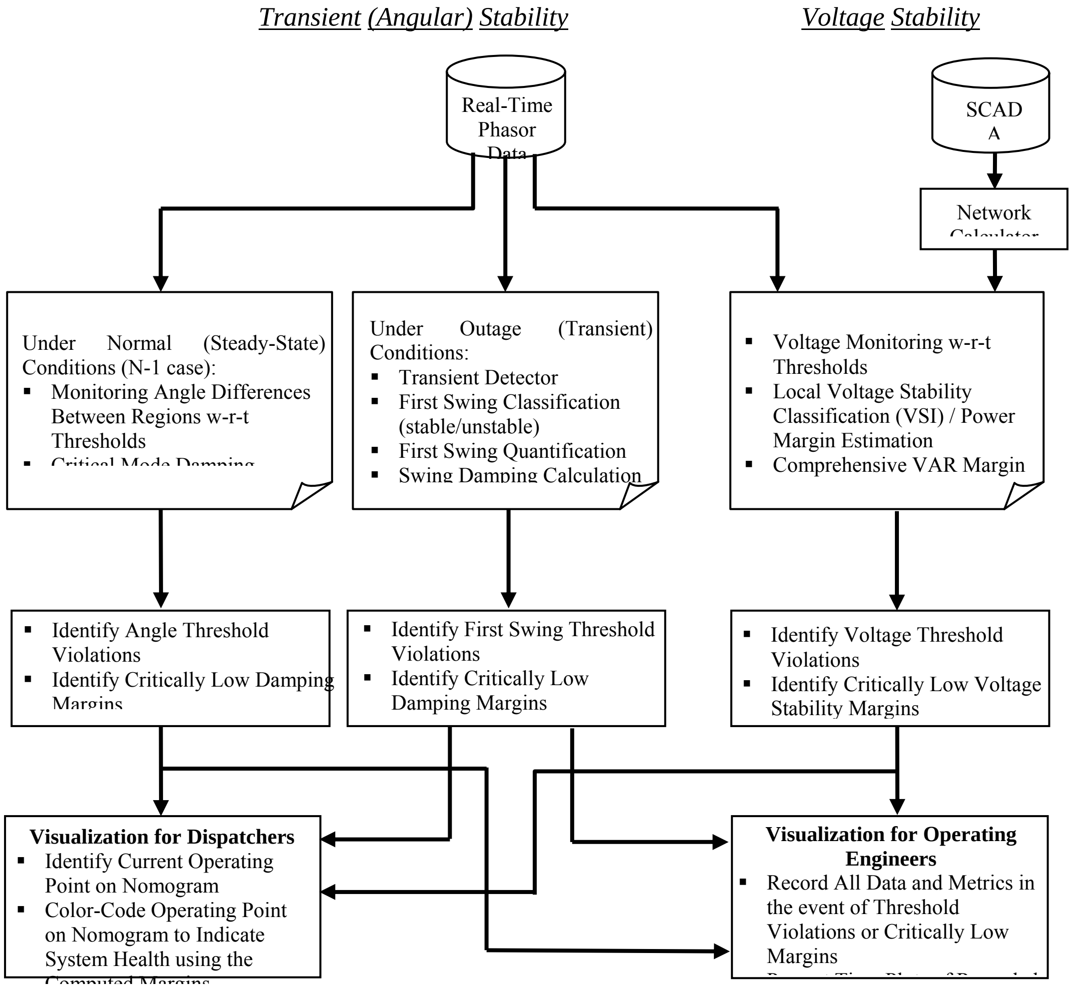

Figure 3: Nomogram Validation Flow Chart.

4.3 STABILITY ASSESSMENT DURING TRANSIENT EVENTS

Transient stability assessment is traditionally performed off-line thru step-by-step time simulations using detailed generator modeling. The computational burden of performing such studies continually and on-line with detailed models is prohibited at present. In addition, they don't provide a continuous quantitative stability measure for a particular case.

Phasor measurement data allows to accurately trace the progression of a transient in real time, once a contingency or disturbance has launched it. The internal generator phase angle can be easily calculated from the voltage and current phasor measurements at the generator buses using the generator's transient impedance. The internal generator phase angle with respect to a reference may result in one of the following outcomes:

1. Increasing/Decreasing Generator Phase Angle without bounds
2. Increasing Oscillatory Generator Phase Angle
3. Decreasing Oscillatory Generator Phase Angle
4. Exponentially Decaying Generator Phase Angle

After the start of a transient swing has been detected, phasor technology can be used to track the initial swing(s) during the first second of the transient using a sliding window and to classify the swing as stable or unstable depending on the resulting outcome. In absence of first swing instability, it will possible to quantify the size of the first swing.

For a fast first swing assessment soon after the transient has been launched (i.e., within a 1 second window), the above mentioned direct approach is adequate to distinguish between stability and instability. However, once the transient has been classified as being first swing stable, a high order autoregressive model can be used over a longer data window to accurately quantify the stability (i.e., calculate the most undamped mode in the system) by sliding the window over the measured power system data to track the modal frequencies and damping in real-time. The damping associated with each of the modes is a measure of the rate at which the transients decay with time and is therefore an indicator of the proximity of the transient to instability. We refer to these indicators as Angle Stability Indices (ASI). Operators can be alarmed if the damping of these modes falls below predetermined thresholds (e.g. 3%, 5% or 10%).

In summary, phasor measurements would be used to dynamically track a transient event at the generator buses, quantify the transient and assess the stability or instability of the current transient using an appropriate metric (i.e., stability indicator). This information can be used to:

a) Provide real time assessment of the stiffness of the system under current operating conditions including measures of margin and swings.
b) Validate compliance with governing criteria such as voltage swing limits and damping.
c) Validate the point on the nomogram corresponding to the contingency once the disturbance has begun and determine the strength of the system following a disturbance.

Given a series of such observations that either belong to the stable or unstable regions as well as a quantification of the degree of stability using a new metric (size of first swing, angular stability index, etc), we can use these data points to extrapolate the boundaries of the nomogram in an efficient manner (for example, preserving the concavity of the boundary). As the number of observed transients in the system increase over time, estimates of the nomogram limits will improve. In this way, a series of observations under different power flow conditions will define the "actual" stability limits of a nomogram. An example of a transient stability assessment algorithm based on phasor technology is summarized in the appendix.

4.4 STABILITY ASSESSMENT UNDER NORMAL CONDITIONS

The techniques described above evaluated the power system health under a transient event. However, transient stability limits are determined such that the system adequately survive contingencies by applying a safety margin (i.e., the limits are developed for the 'N-1' scenario). Since operators will be continuously operating the system under safe areas the technique used for transient events will not be sufficient to assess the strength of the system under normal conditions.

Currently, the restrictions on the nomograms are power flows across interfaces. However, angle differences across particular interfaces under normal conditions are important monitoring metrics because large angle differences between key points in the power system are indicators of proximity to instability in the power system. These angle differences will only increase under contingencies. The offline planning studies performed to develop the existing nomograms may be used to identify monitoring points in the system as well as define thresholds on angle differences across critical interfaces. Phasor data gathered at the two ends of the interfaces can then be used to track the angle differences across the interface with respect to the predetermined thresholds and validate the existing nomograms.

In addition, under normal conditions, low frequency electrical modes exist in the system that are of interest because they characterize the stability of the power system and limit the power flow across regions. While there is a danger that such modes can lead to instability in the power system following a sizable contingency in the system, there is also the risk of these modes becoming unstable (i.e., negatively damped) due to gradual changes in the system. The ability to continuously track the damping associated with these low frequency modes in real-time and under normal conditions would therefore be a valuable tool for dispatchers and power system engineers. Operators would be alarmed if the damping of these modes falls below predetermined thresholds (e.g. 3% or 5%). The low frequency oscillations are best observed from data corresponding to power flows thru long transmission lines that represent the weak links between densely interconnected regions in the power network.

As in the transient case, a sliding block processing technique to track the modal frequencies and damping in real-time will be used here as well. However, instead of the generator angles, the measured power flows thru long weak links in system that are usually prone to these low frequency oscillations, will be the signals used in the analysis. The Low Frequency Oscillation Stability Index (LFSI) can then be defined as least positive damping ratio (i.e. the most unstable mode). A window length of about 20 minutes is shown to give accurate estimates of the modal frequencies and damping. The block diagram for the proposed algorithm is shown in figure 9.

4.5 VOLTAGE STABILITY ASSESSMENT

Phasor technology offers the ability to accurately measure voltages at various points across the power network at a very high rate. Furthermore, phasor measurements at a load bus contain enough information to accurately detect the voltage stability margin at the bus and define a Voltage Stability Index (VSI) for the bus. It is a well-known fact that for a two-bus system with a constant power load (i.e., a constant source behind an impedance and a load), the maximum loadability condition occurs when the voltage drop across the source impedance is equal to the voltage across the load. Hence, the idea is to use the phasor measurements at the bus to dynamically track in real-time the two-bus equivalent of the system. In particular, given the voltage and current phasor measurements at the bus (‘$\overline{V}$’ and ‘$\overline{I}$’), it is possible to estimate the parameters of the Thevenin equivalent system (‘$\overline{E}_{th}$’ and ‘$\overline{Z}_{th}$’) from a sliding window of discrete samples using a recursive least squares scheme (RLS). The maximum loadability condition corresponds to the case when ‘$E_{th} = 2V$. Furthermore, since the Thevenin parameters are being tracked dynamically, they reflect any changes that may occur in the power system operating conditions and consequently provide the most accurate assessment of loadability estimates.

The very same methodology can also be used to compute Voltage Stability Index for the power transfer across a tie-line. By assuming a directional flow across the line, the line is replaced by a fictitious sink and source at the sending and receiving ends of the line respectively that draw the same power as the tie-line flows. One can now replace the system with its Thevenin equivalent and compute the VSI for the tie-line flows as well.

Finally, if we assume that ‘Z_{th}’ isn’t changing significantly, we can also compute a Power Margin (PM) from the two-bus equivalent as:

$$\Delta S = {(E_{th} - Z_{th} I_{th})^2} \big/ {4Z_{th}}$$

Again, operators may be alarmed if these indices fall below predetermined thresholds (e.g. 5% of the current load/flow).

In addition, for a more rigorous analysis and in anticipation of the next contingency, given SCADA data and the system model, it is possible to perform a real time perturbation analysis under the current operating conditions and consequently compute the reactive margins at the desired buses in the system. Although, this approach is more rigorous in its assessment than the one suggested above, it requires supplementary information (i.e., system model and global system state) and more time to solve.

4.6 MULTIVIEW VISUALIZATION

Each of algorithms described in the previous sections provide new real-time metric(s) for assessing the health of the system. Observation points around the boundaries of the nomogram are of most value for validation purposes. While the boundaries of the nomogram provide a discrete secure/insecure classification, the proposed metrics also quantify the degree of such a classification during contingencies and during normal conditions. For visualization purposes, we intend on providing this additional information thru a color assigned to the operating point on the nomogram based on a color legend for the corresponding metric.[2] As more observations are made over time, they will serve as additional validation points and will gradually create a collection of color-coded points that will populate the nomogram. It will also be possible to use these quantified metrics for validation points at different locations on the nomogram and extrapolate new points to validate or enhance the nomogram.

Described below are samples of what the nomogram validation displays for the application may include. The actual content of displays associated with a nomogram that is to be validated will depend on the whether the nomogram was developed with transient or voltage stability considerations as well as the algorithms chosen to validate it.

Transient Stability Assessment Display: Whenever a transient is launched in the system, the application may:

1) Notify the user that a transient has been detected
2) Dynamically tracks the swing and classifies it as stable and unstable at any or all the generators
3) Identify the most unstable swing in the system
4) Quantify the health of the transient based on the new metric by identifying swing and damping margins (e.g., size of first swing or damping ratio).
5) Validate the nomogram(s) with the new observation point

Figure 4 is a sample display where a nomogram in the large panel on the left (referred to as the Real-Time Monitoring panel) is used to illustrate the application. Whenever, a transient is detected, the corresponding observation point is placed onto the nomogram and this latest validation point is emphasized by a border around it. In addition, the color of the new point is based on a legend that quantifies the most critical mode (i.e., most undamped mode) associated with the transient.

In the top right panel, for each of the monitored swings, the most unstable swing is measured and plotted at a high resolution as a function of time. In the bottom right panel, the computed damping associated with the most unstable modes is tracked in real time after the transient event. The x-axis in this plot is the damping and the y-axis is the corresponding frequency of the mode. Any modes to the left of the y-axis are negatively damped and are therefore stable. However, modes to the right of the y-axis are positively damped and indicative of instability in the system. Also shown on this plot are loci of constant damping ratios that behave as thresholds for these modes. The operator is alarmed whenever the modes cross these thresholds.

Finally, across the bottom of the display (referred to as the action panel), a moving one minute window of all the monitored generator phase angles are displayed in real time. Provision will be made for changing the reference bus where phasor data is provided. The

[2] Depending on the nomogram and the algorithm, multiple metrics may be appropriate for validation purposes

information shown in each of the panels is also archived in tabular text format and can be viewed by selecting the corresponding panel tab shown above the bottom action panel.

This is only a sample of what the application can do. Actual displays will be determined based on the needs and requirements of the user or the type of nomogram for which the application is developed for.

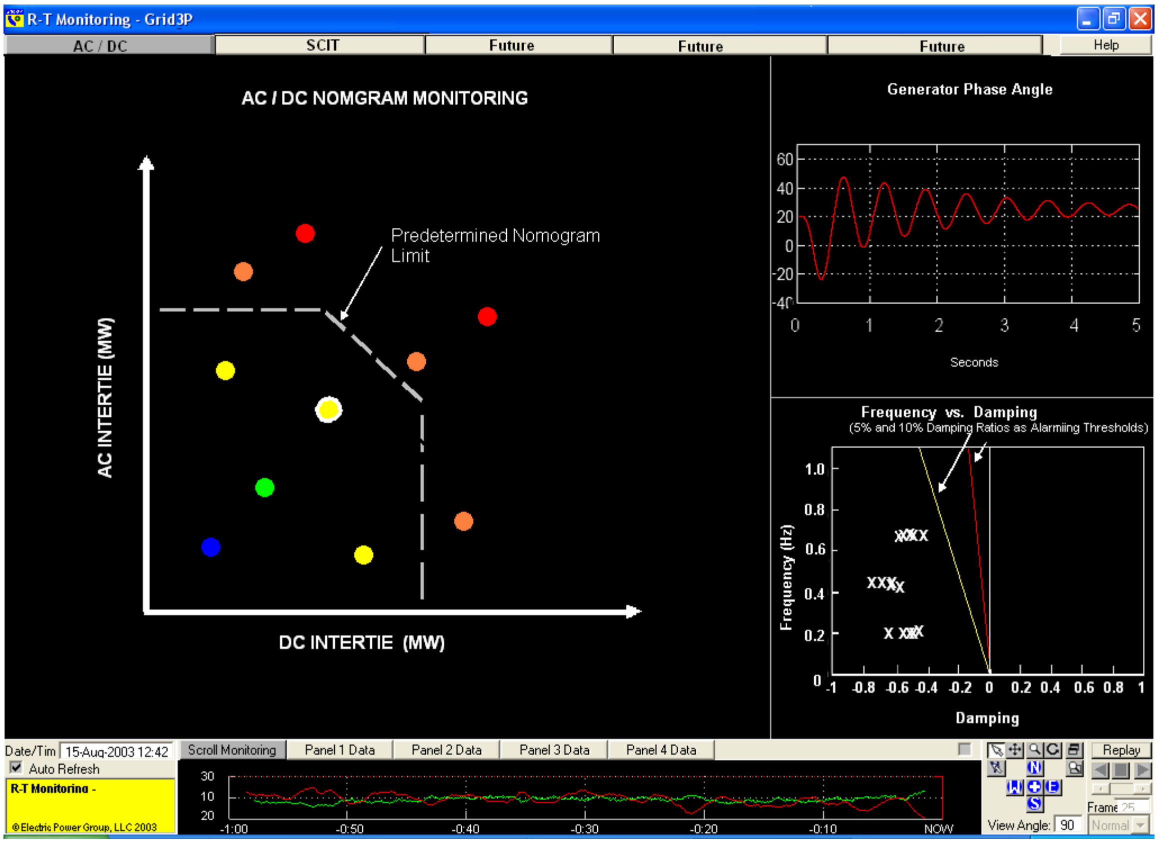

Figure 4: Sample Nomogram Display based on Transient Stability Considerations.

Voltage Stability Assessment Display: The application continuously measures the phasor voltages and currents at key load buses/transfer paths and uses a sliding window of gathered measurements to dynamically estimate the Thevenin parameters for the system. The system parameters are used to calculate voltage stability indices as well as power margins. The smallest value among all the voltage stability indices that have been computed at the load bus/transfer paths is the one closest to voltage instability and therefore defines the voltage stability index for the entire system.

Figure 5 is a sample display for validation of nomograms developed with voltage stability considerations. As with transient stability display, whenever a significant change is measured in the nomogram parameters, a new observation point is added onto the nomogram. The color of the new point is based on the computed voltage stability index for the system under the current system conditions (a voltage stability index of one being the maximum loadability condition).

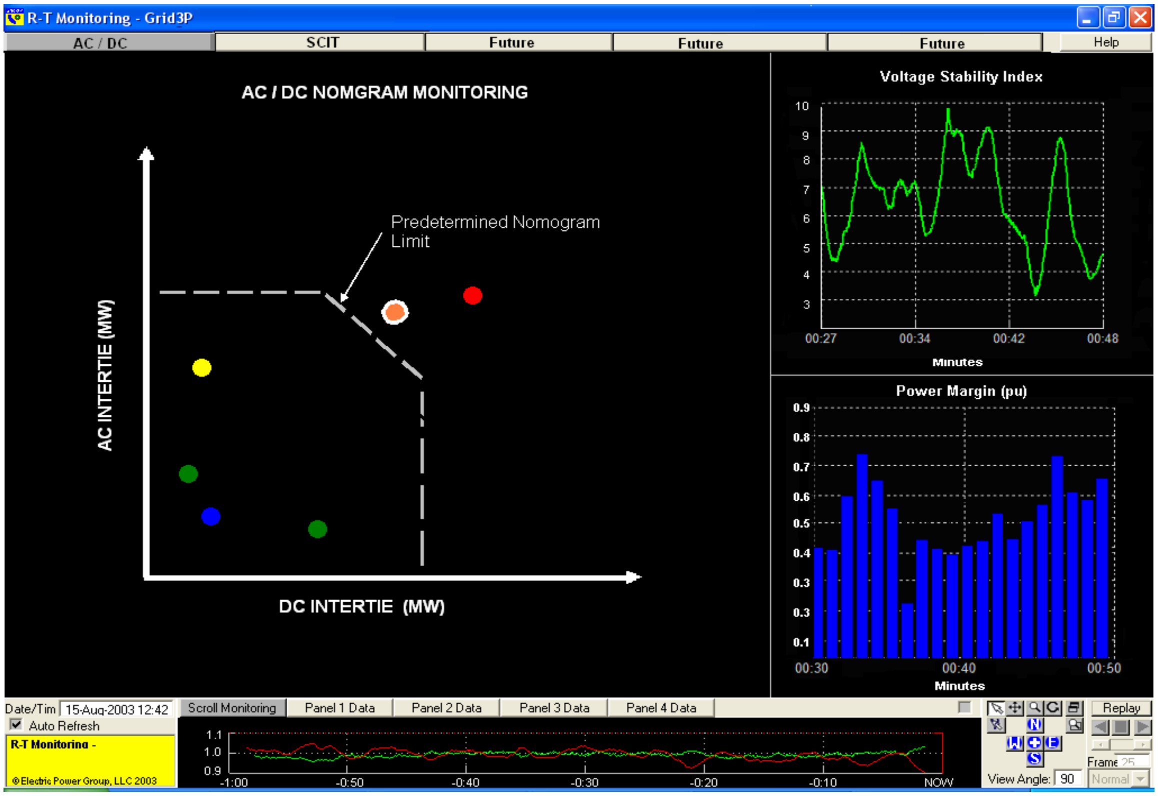

Figure 5: Sample Nomogram Display based on Voltage Stability Considerations.

In the top right panel, a time history of the voltage stability index for the system is provided. In the bottom right panel, the time history of the corresponding power margin is shown as a bar graph plot as a well. Minimum thresholds on both these values maybe set and the user is alarmed whenever they are violated.

Finally, across the bottom of the display, a moving one hour window of the computed impedances (‘Z_{th}’ and ‘Z_{app}’) is displayed in real time. The information presented in each of the displays is also available in tabular text format by selecting the corresponding panel tab shown above the bottom action panel.

5.0 HARDWARE, SYSTEM AND APPLICATIONS SOFTWARE CONCEPTUAL OVERVIEW AND ARCHITECTURE

The figure below shows a conceptual overview of the hardware, system and application software configuration for the applications being developed for CAISO.

The architecture of the CAISO synchronized phasor measurement system is made of the three computers shown at left side on the figure below and the system and application software to reside in each computer is shown at the right side of the same figure. The workstation shown in the second diagram for the first phase has been completed, tested and delivered to CAISO operating engineers at Folson. CERTS is currently working with CAISO in the deployment for the phases 2 and 3 shown in the second figure.

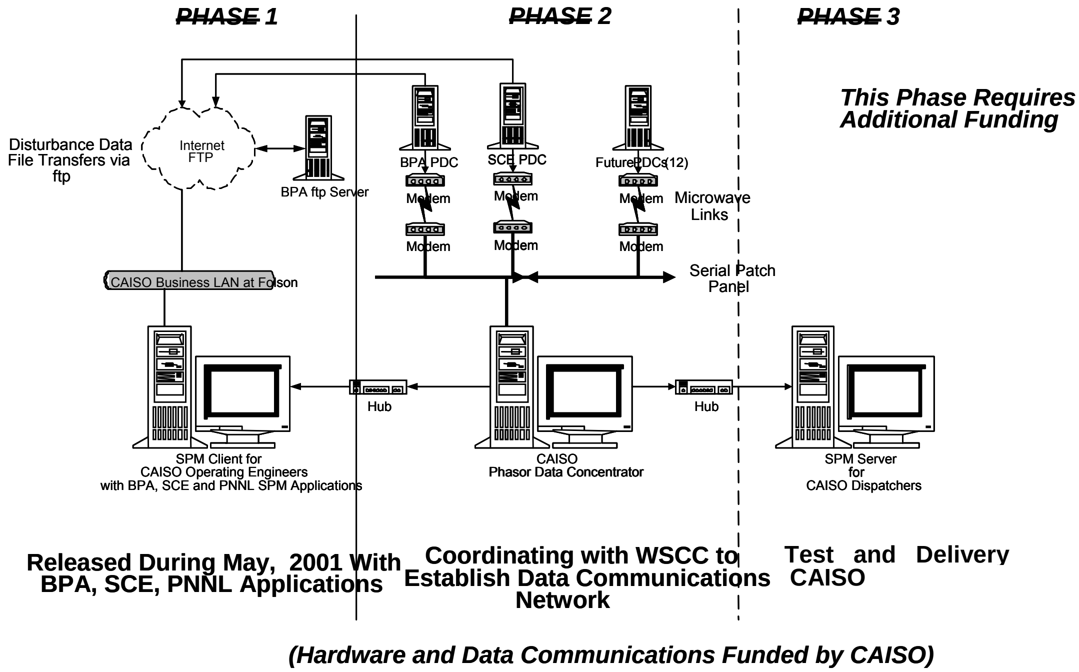

Figure 6: Hardware and Data communications.

6.0 DOCUMENTATION AND TRAINING

Functional specification, the design specification and user guide will be provided on completion.

7.0 DEPLOYMENT SCHEDULE

TBD

APPENDIX

TRANSIENT STABILITY

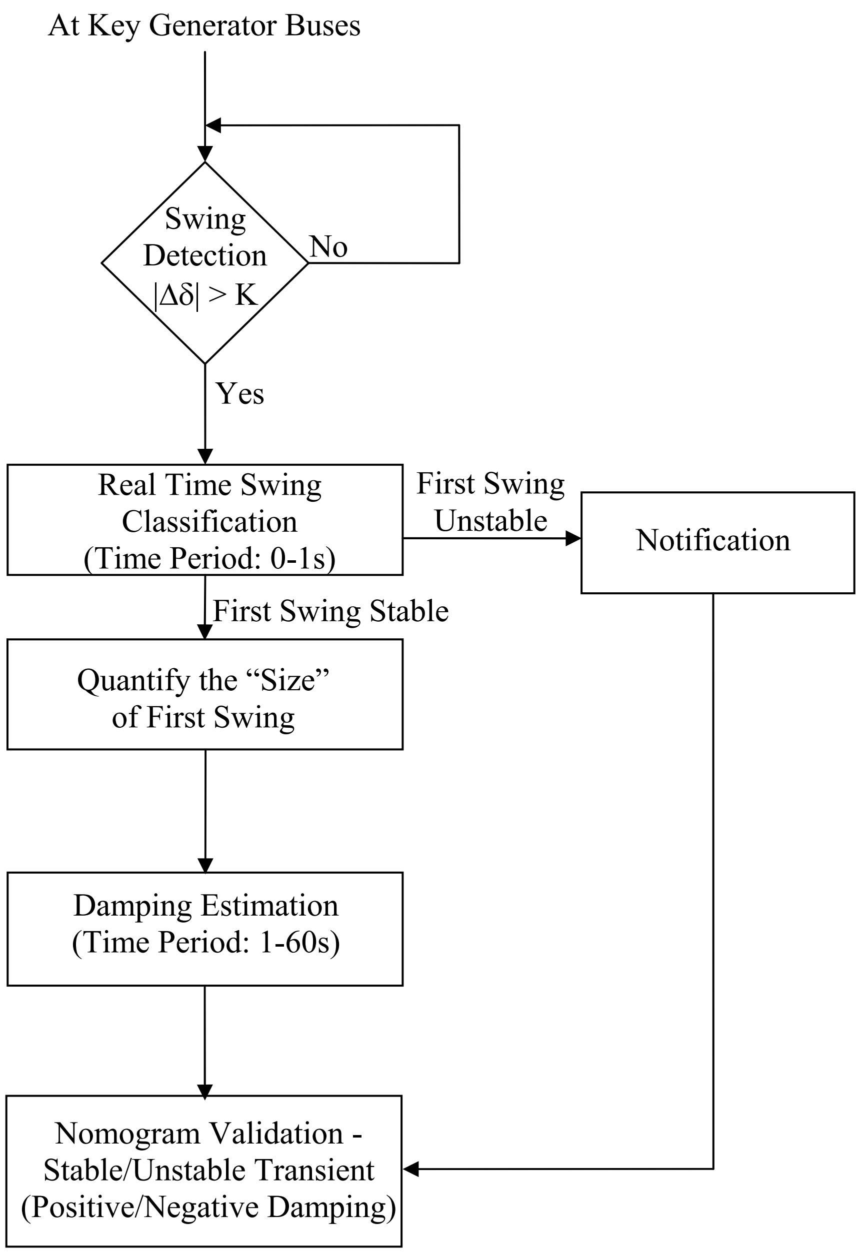

Figure 7: Sample Flow Chart for Transient Stability Assessment Based on Phasor Measurements.

VOLTAGE STABILITY

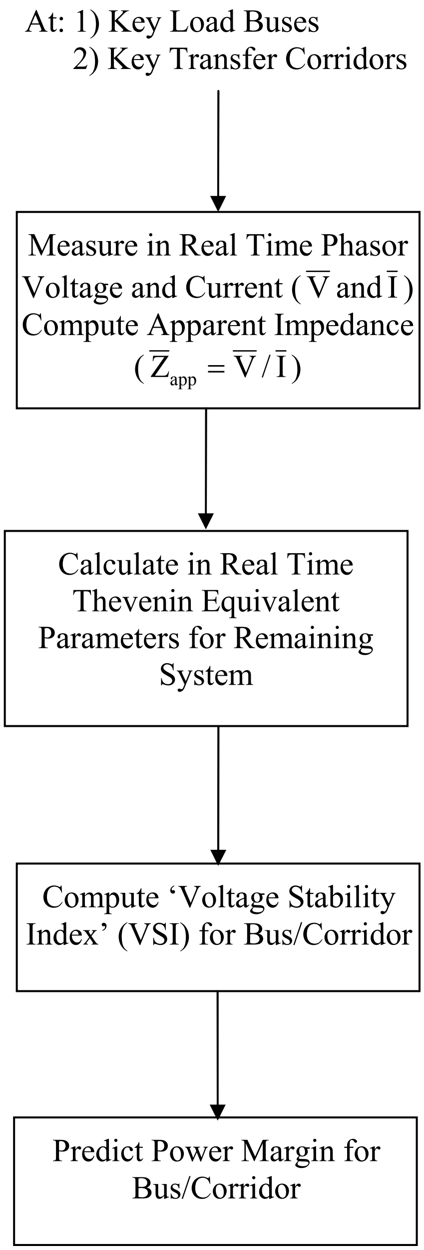

Figure 8: Sample Flow Chart for Voltage Stability Assessment Based on Phasor Measurements.

SYSTEM DAMPING UNDER NORMAL CONDITIONS

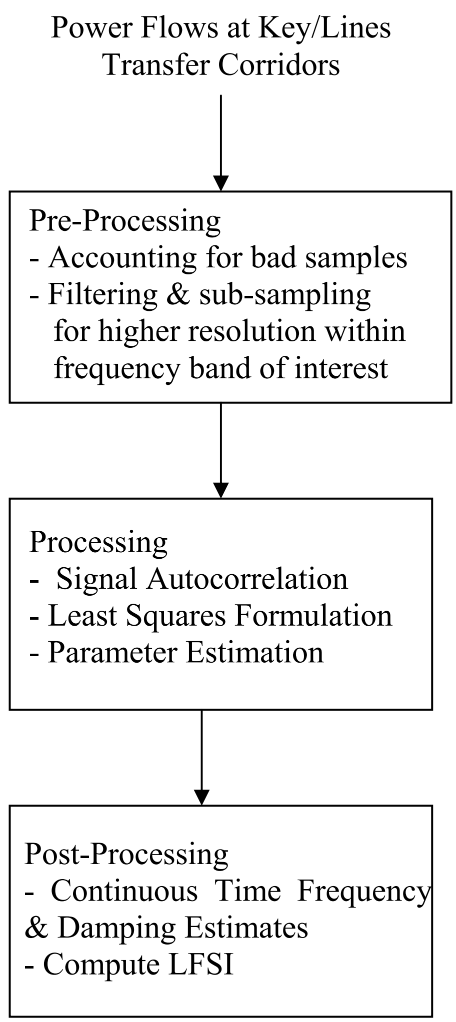

Figure 9: Algorithm for Computing the Damping Associated with the Low Frequency Oscillatory Modes Under Normal Conditions.